Aerosol Effects on Cold Season Orographic Precipitation and Water Resources in the Western U.S.

PI: L. Ruby Leung, Pacific Northwest National Laboratory
Co-Is: Daniel Rosenfeld, Hebrew University of Jerusalem
Steven J. Ghan, Pacific Northwest National Laboratory

Project hypothesis: Aerosols can reduce the orographic enhancement of precipitation in mountains downwind of urban areas and result in <u>redistribution</u> of precipitation from the ridges to the semi-desert lowlands, and a <u>net loss</u> of precipitation and snowpack in the mountains.

Objectives: Combine data analysis and modeling to test the hypothesis and address the following questions:

- What aerosol effects on the regional water cycle can be inferred from historical and remote sensing data? How well can these effects be detected from observational data?
- What cloud-aerosol interaction and microphysical processes are important in determining the effects of aerosols on cold season orographic precipitation? How sensitive are the aerosol effects to synoptic conditions and orographic features?
- What are the potential impacts of greenhouse warming and air pollution on water resources in the western U.S.?

Deliverables:

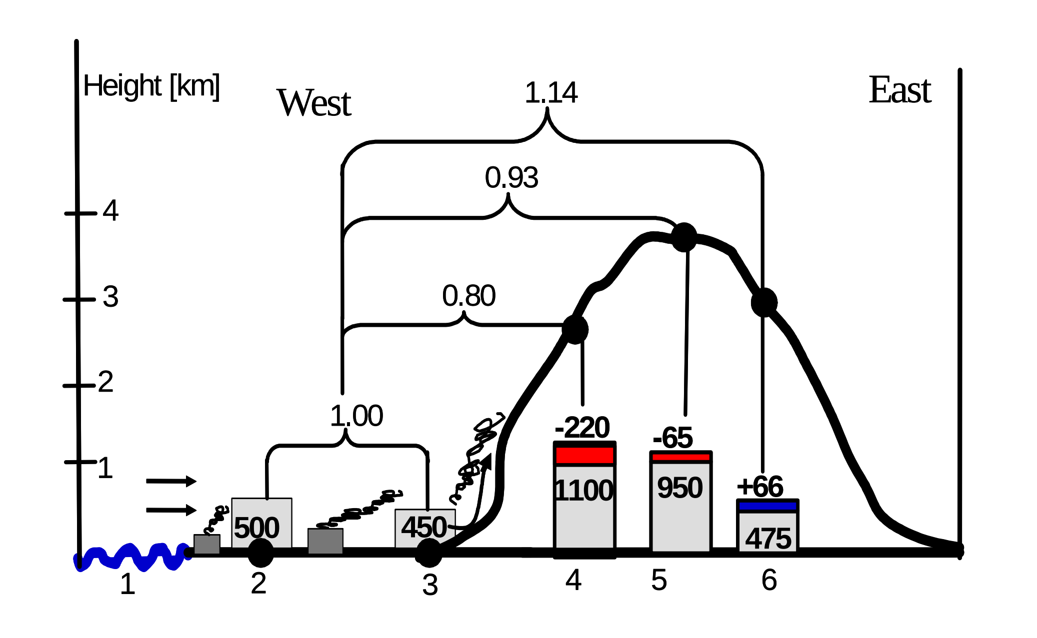
- Data analysis of historical climate records and satellite data to determine the decreasing trends in orographic enhancement of precipitation, and connecting the reduced orographic precipitation with changes in cloud properties to elucidate the processes that may have caused the trends.
- Numerical simulation of aerosol effects on orographic precipitation and mountain snowpack based on regional climate modeling with prescribed aerosol distribution derived from model simulations and satellite data

Technical Approach

Data Analysis

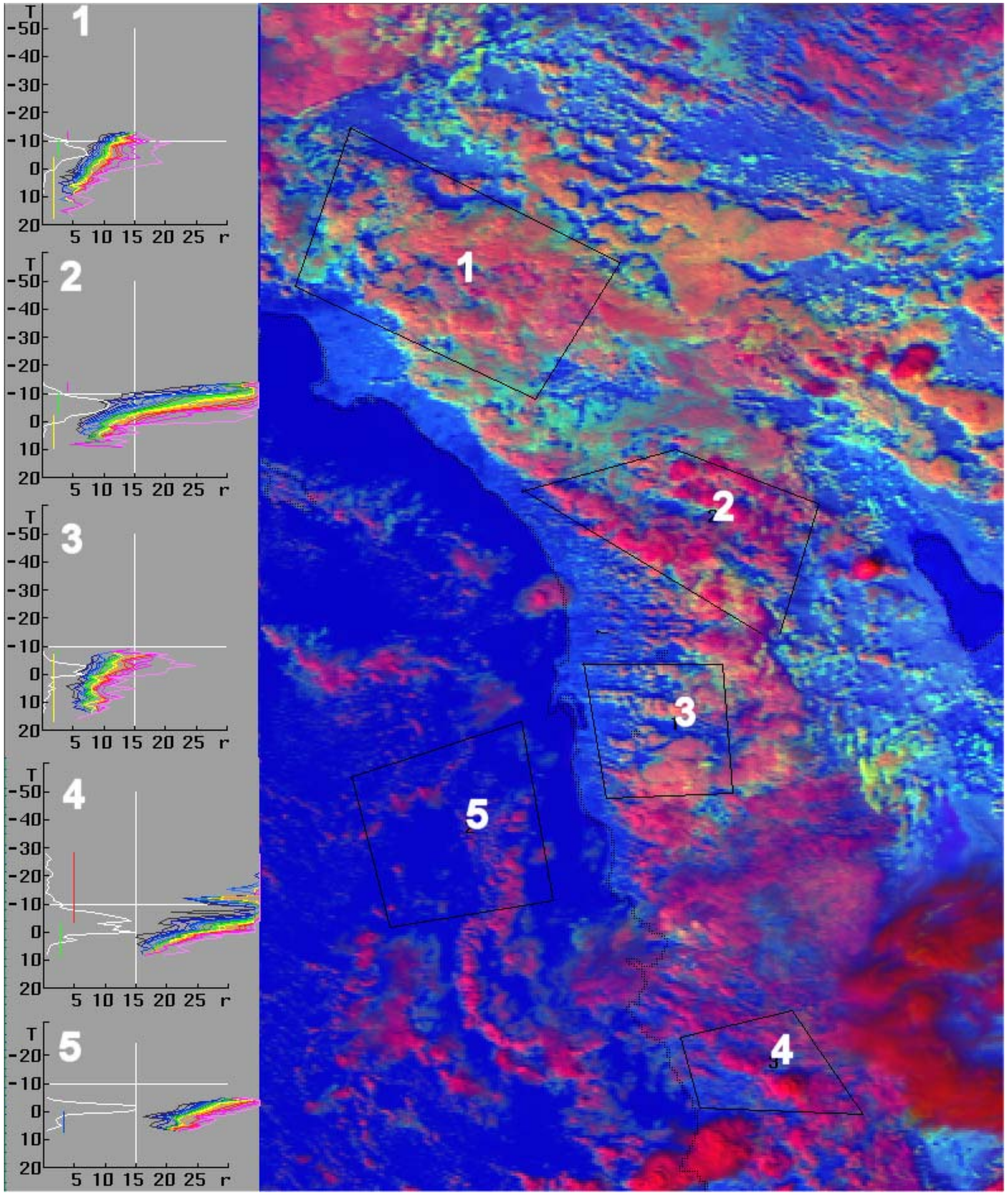
- Analysis of satellite data including aerosol optical depth, effective cloud droplet radius, and precipitation structure
- Analysis of historical records of precipitation, temperature, snowpack, and synoptic conditions to elucidate long term trends
- Statistical analysis of long term trends and climate variability for attribution of aerosol and greenhouse gas effects

Topographic cross section showing effects of urban air pollution on precipitation as clouds move from west to east to the Sierra Nevada and eastern slopes



Topographic cross section showing the effects of urban air pollution on precipitation as the clouds move from west to east from the coast to the Sierra Nevada and to the eastern slopes. The boxes show the amount of annual precipitation (mm/year) in each topographic location, and the numbers above them show the loss or gain of precipitation (mm/year) at each site. Maritime air (zone 1) is polluted over coastal urban areas (zones 2, 3), with no decrease in precipitation. The polluted air rises over mountains downwind and forms new polluted clouds (zone 4), with decreases of 15%-20% (losses of 220 mm/year) in the ratio between the western slopes and the coastal and plain areas. The clouds reach to the high mountains (zone 5). All of the precipitation is snow, with a slight decrease of 5%-7% (loss of 65 mm/year) in the ratio between the summits and the plain areas. The clouds move to the high eastern slopes of the range (zone 6), with an increase of 14% (gain of 66 mm/year) in the ratio between the eastern slopes and the plain. The net loss is dominant. (From Givati and Rosenfeld 2004).

NASA ENERGY AND WATER CYCLE STUDY



Analysis of Satellite Data

The reduction of cloud drop effective radius as the clouds move from the Pacific coast to Los Angeles (Area 1) and San Diego (Area 3), as observed by NOAA-16 on February 23 2004, 21:45 UTC. Areas 2 and 4 show areas with relatively pristine clouds with a lot larger effective radius exceeding the 14-mm precipitation threshold. For comparison, Area 5 is over the ocean, for reference of how highly maritime clouds look like. The image is a composite of visible channel modulating the red, 3.7 mm reflectance modulating the green, and 11 mm brightness temperature modulating the blue. Therefore, clouds with larger particles are colored more red. The color scheme and significance of the T-Re relations is described in Rosenfeld and Lensky (1998).

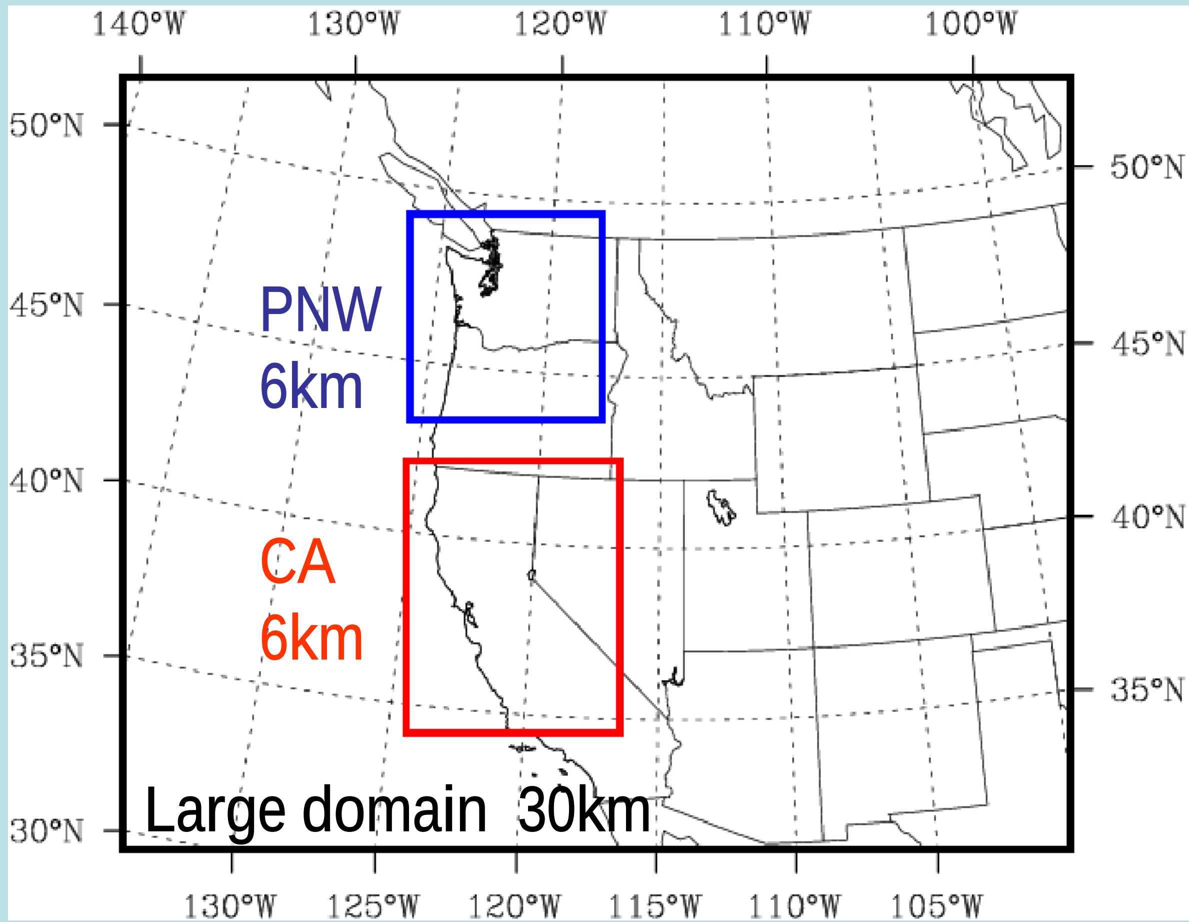
Technical Approach

Numerical Modeling

- Prescribe aerosol distribution and composition based on simulation by a global atmosphere-chemistry-aerosol model (MIRAGE) and scale the spatial distribution by satellite measurements of aerosol optical depth
- Introduce a prognostic treatment of cloud droplet number that relates cloud droplet number and aerosol concentration in a regional climate model – the Weather Research and Forecasting (WRF) model
- Modify cloud microphysics schemes to relate cloud droplet number and autoconversion rate
- Aerosol direct effects will be treated using the CAM3 radiation in WRF
- Perform sensitivity experiments to examine the effects and uncertainties arising from the various treatments of the physical processes that relate aerosols and precipitation.
- Perform long term simulations with and without aerosol indirect effects.

Simulation of Cold Season Orographic Precipitation

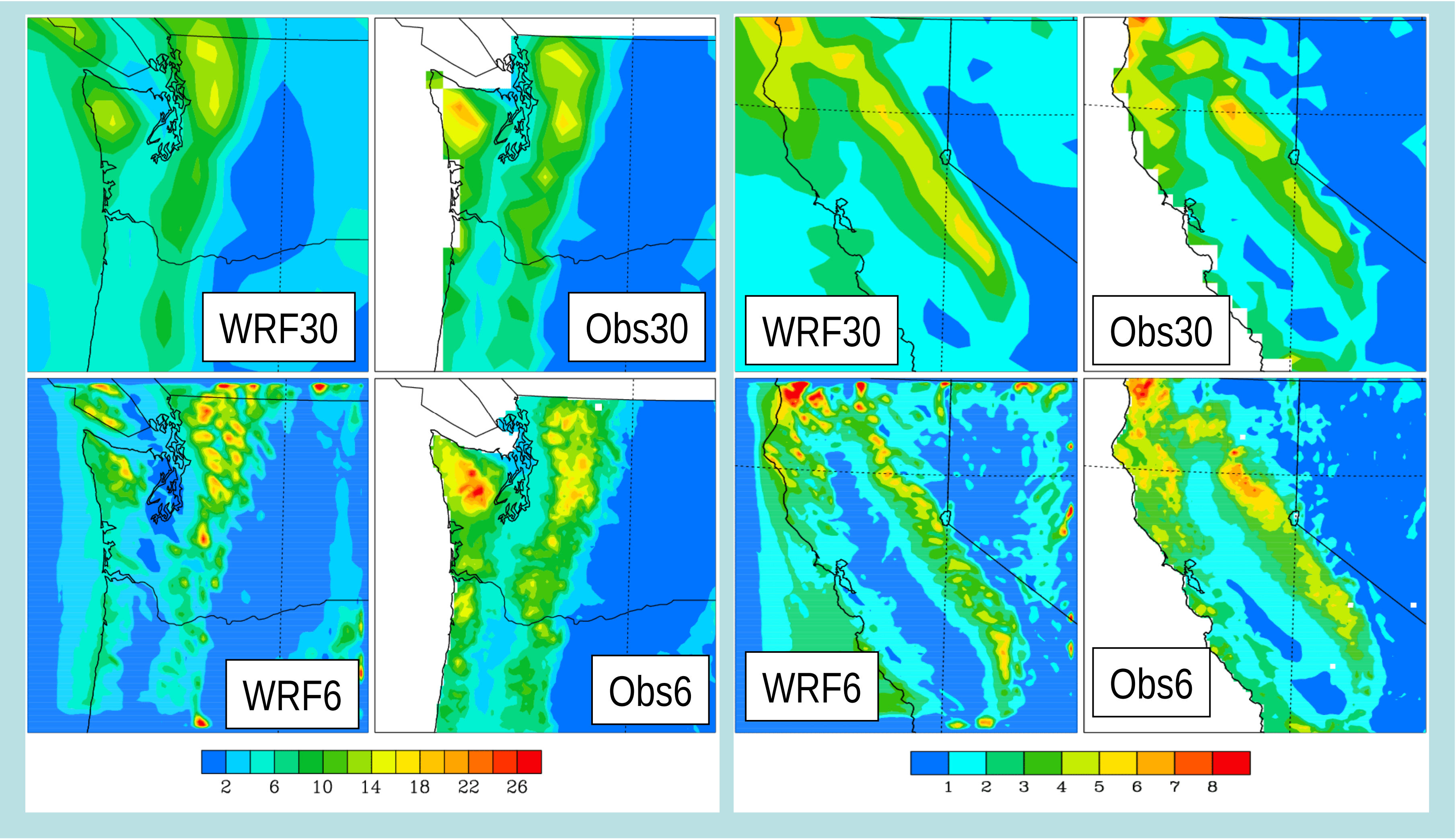
- Large domain at 30 km resolution (WRF30) driven by NCEP/NCAR reanalysis
- One-way nesting applied to two nested domains at 6 km resolution (WRF6)
- Simulation period: 10/1/1990 – 3/31/1991



NASA ENERGY AND WATER CYCLE STUDY

NEWS

Mean Precipitation (mm/day)



NASA ENERGY AND WATER CYCLE STUDY

Data set needs (particularly large data sets – include potential sizes):

- TRMM, MODIS, AVHRR data
- Historical temperature, precipitation, snowpack, and meteorological data
- Global reanalysis data for driving regional climate model
- GCM model outputs (meteorology and aerosols) for driving regional climate model

Project outputs (project results that may be made available to the NEWS team for subsequent use – include potential size/resource requirements):

- Analysis of effective cloud drop radius, aerosol optical depth, and precipitation structure based on remote sensing data
- Analysis of historical precipitation and snowpack trends
- Regional climate model outputs for analysis
- WRF model with prognostic cloud droplet number and modified cloud microphysics

Potential collaborations (with NSIT, other NEWS projects, etc.) **:**

- "Evaluation of NASA's Global Water Cycle Data: Interannual Variability, Interdecadal Changes and Trends" (Bosilovich)
- "Global Precipitation Analysis for Climate and Weather Studies" (Adler)
- "A Merged Atmospheric Water Vapor Data Set from the A-Train" (Fetzer)
- "An A-Train Integrated Aerosol, Cloud, and Radiation Data Product" (Wielicki)

Important outside linkages/resources (outside the NEWS team) **:**

- NOAA GAPP project on "Modeling the Topographic Influence on Cold Season Precipitation and ENSO Effects in the U.S. Pacific Northwest" (PI: Leung)
- NASA project on "Linking Air Pollution to Regional and Global Climate Change: The Absorbing Atmospheric Brown Cloud (ABC) as a Test Case" (PI: Ramanathan; co-PIs: Leung & Carmichael)
- Chair, Regional Climate Modeling Working Group, Weather Research and Forecasting (WRF) Model
- Member, WRF Research Applications Board
- Member, GAPP Science Advisory Panel
- co-Chair, PUB Working Group on Orographic Precipitation, Surface and Groundwater Interactions, and Their Impacts on Water Resources
- Member, Climate Impacts Group, University of Washington

Expected contribution to the NEWS objective:

- Strengthen observational evidence of aerosol effects on water cycle
- Improved understanding and attribution of observed changes in water cycle
- Improved process understanding of water cycle changes (precipitation and snowpack) induced by aerosols effects on orographic precipitation
- Improved understanding of the impacts of aerosols on mountain water resources
- Improved understanding of potential changes of mountain water resources in the future

Issues, needs, and concerns (to be discussed in breakouts, teaming discussions, etc.):

- $$$ for both analysis and modeling
- Computational resources (disk space and CPUs) for numerical modeling (high spatial resolution is desirable)
- Address uncertainty in numerical modeling of aerosol effects